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Technical Bulletins provide information to States, compact regions, and other interested parties on issues related to the development of low-level radioactive waste disposal facilities. The Bulletins distribute information that is either of immediate concern to the States and compact regions, or not suited to more formal reports. These Bulletins are published on an as-needed basis.

The objective of this Technical Bulletin is to provide States and compact regions with information regarding low-level radioactive waste disposal technologies used outside the United States.

LOW-LEVEL RADIOACTIVE WASTE DISPOSAL TECHNOLOGIES USED OUTSIDE THE UNITED STATES

Kelli J. Templeton
Sue J. Mitchell
Peter M. Molton
Inga W. Leigh

Introduction

Low-level radioactive waste (LLW) disposal technologies are an integral part of the waste management process. In the United States, commercial LLW disposal is the responsibility of the State or groups of States (compact regions). The United States defines LLW as all radioactive waste that is not classified as spent nuclear fuel, high-level radioactive waste, transuranic waste, or by-product material as defined in Section II(e)(2) of the Atomic Energy Act. LLW may contain some long-lived components in very low concentrations. Countries outside the United States, however, may define LLW differently and may use different disposal technologies. The following information outlines the LLW disposal technologies that are planned or being used in Canada, China, Finland, France, Germany, Japan, Sweden, Taiwan, and the United Kingdom (UK).

Canada

The major responsibility for management of LLW in Canada, including disposal, rests with the waste producers. In Canada, LLW is defined as all radioactive waste except spent fuel from nuclear reactors and uranium mine residues. LLW is divided into three classes according to its half-life: (Class I) low radionuclide concentrations with a half-life of 150 years, (Class II) waste with a half-life up to 500 years, and (Class III) long-lived radionuclides (half-life greater than 500 years) (Schneider 1991).

There are currently no LLW disposal facilities in Canada. The LLW is being stored in facilities located on the waste generators' sites, or at Atomic Energy of Canada Limited (AECL) research sites. An application to build a LLW disposal facility at the Chalk River Laboratories of AECL is under review by the Atomic Energy Control Board, the Federal agency that regulates the Canadian nuclear industry. The facility will be known as the Intrusion Resistant Underground Structure (IRUS) (Figure 1). The proposal is to build a single facility. Proposals to build other facilities in the future will be reviewed separately.

The proposed IRUS facility will consist of a reinforced concrete, in-ground module with a permeable floor. The modules will be approximately 30 meters long, 20 meters wide, and 9 meters deep, with a total volume capacity of 2,000 cubic meters. Each module will contain packaged waste primarily in the form of 200-liter steel drums, bales, and standardized waste containers. Space between the waste packages will be filled with sand, and the base of each unit will be compacted buffer material. During operation, an IRUS unit will have a portable building over it and a crane for handling the waste packages. After the module is filled, the portable building will be removed to be used on other modules, and the filled module will be covered with a concrete cap overlaid with an engineered cover containing barrier and drainage features. Construction of the IRUS facility is not expected to begin before 1995.

People's Republic of China

Disposal of LLW in China is done by regions due to the large size of the country. China National Nuclear Corporation is responsible for site selection, construction, and operation of the

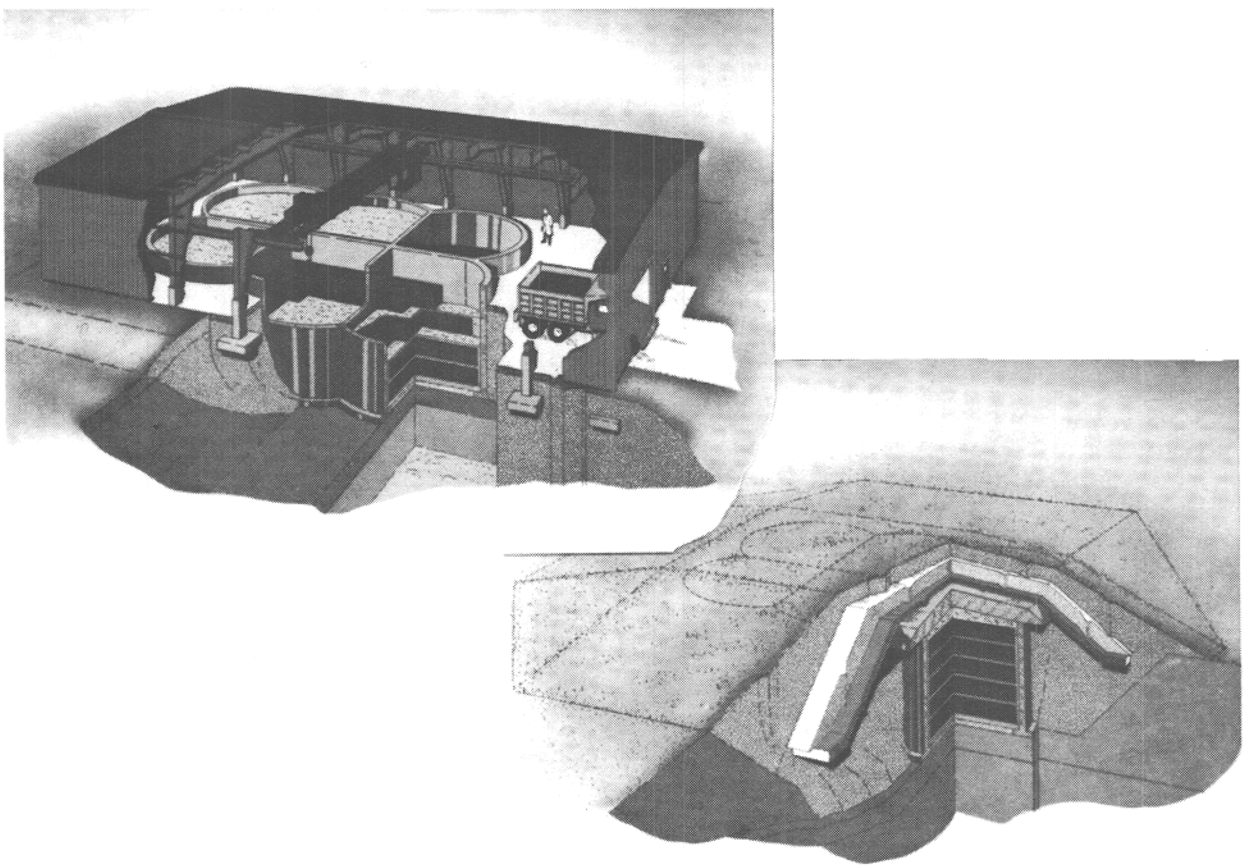


Figure 1. Proposed IRUS belowground concrete vault in Canada during operational phase and post closure phases (courtesy of AECL Research).

regional disposal facilities. The National Authority of Environmental Protection is responsible for supervising LLW disposal activities (Ziqiang 1993). LLW is defined in China as waste having radioactivity between one hundred millionth to one hundred thousandth of a curie in a liter of LLW (Schneider 1991).

China currently disposes most of its LLW in shallow trenches in the ground. Future LLW is planned to be disposed of in four regional shallow land disposal sites. These disposal facilities are planned to be built in northwest China, southwest China, south China, and east China. Investigations are complete for the northwest disposal site, which is a dry region in the Gobi Desert in the Taishon district. Investigations are underway for the eastern site in Zhejiang province near Shanghai, which is a wet region.

In addition, in situ immobilization is planned for use where the disposal site is near the waste generation site. Lanzhou reprocessing facility in the Gobi Desert is planning to implement this technology. Lanzhou has groundwater about 40 meters deep, so 10 concrete trenches or "silos" underground with dimensions of $8 \times 8 \times 6$ meters will be built. The waste will be covered with dehydrating additives and cement. Once full, each silo will be covered with 1 meter of clay, a concrete cap, and then 7 meters of soil (Schneider 1991).

Finland

Finland's policy for LLW states that disposal facilities will be located and managed at the nuclear power plant sites. However, the Federal government will assume responsibility for these facilities upon closure and proof of safety. The two nuclear power utilities with responsibility for managing Finnish LLW are Teollisuuden Voima Oy (TVO) and Imatran Voima Oy (IVO), at the Olkiluoto and Loviisa nuclear power plant sites, respectively. Both utilities have their own waste management plans but different time schedules for implementation. Prior to operation of the disposal facilities, the utilities stored the LLW onsite.

The underground disposal facility (repository) on Olkiluoto Island in southwest Finland is located in hard rock less than 1 kilometer from the two-unit nuclear power plant (Figure 2). Construction of the repository started in April 1988 and commissioning was in May 1992. A vertical silo-type cavern design was favored because of the host rock structure. Two separate silos were constructed at a depth of 60 to 100 meters with a diameter of 24 meters and a height of 34 meters. One silo will be used for disposal of intermediate-level radioactive waste mixed with bitumen and the other for dry LLW. The silo for the bituminized waste will be lined with a 60-centimeter, reinforced-concrete wall that will function as an extra barrier. No backfilling will be used inside the concrete silo, but the empty space between the concrete silo and the rock will be filled with crushed rock. The waste in both silos will be packaged in concrete boxes containing 16 drums each.

The repository planned for the Loviisa site on the island of Hästholmen began to be excavated in February 1993 (Figure 3). The bedrock on the site consists of granite with groundwater with two zones of different salinity. The boundary between the two zones consists of a fracture zone varying between 60 and 140 meters. The repository will be constructed at a level 110 meters below the gently dipping fracture zone. Unlike Olkiluoto, horizontal tunnels are more suitable for this repository. The Loviisa repository will consist of a cavern for immobilized wet waste and tunnels for dry waste. The repository cavern will have engineered barriers of concrete containers, concrete walls, and a backfilling of crushed rock.

France

Radioactive waste in France is classified into three categories: A, B, and C. Category A is most like the United States' definition of LLW; it includes short-lived waste of low- and intermediate-level radioactivity with half-lives primarily less than 30 years (Schneider 1991). The past

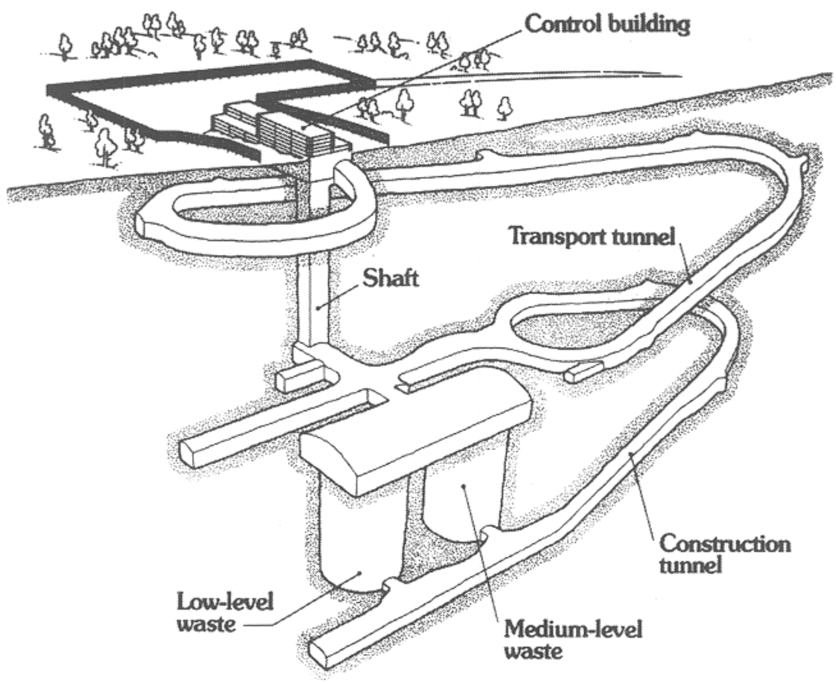


Figure 2. The VLJ repository operated by TVO (courtesy of TVO).

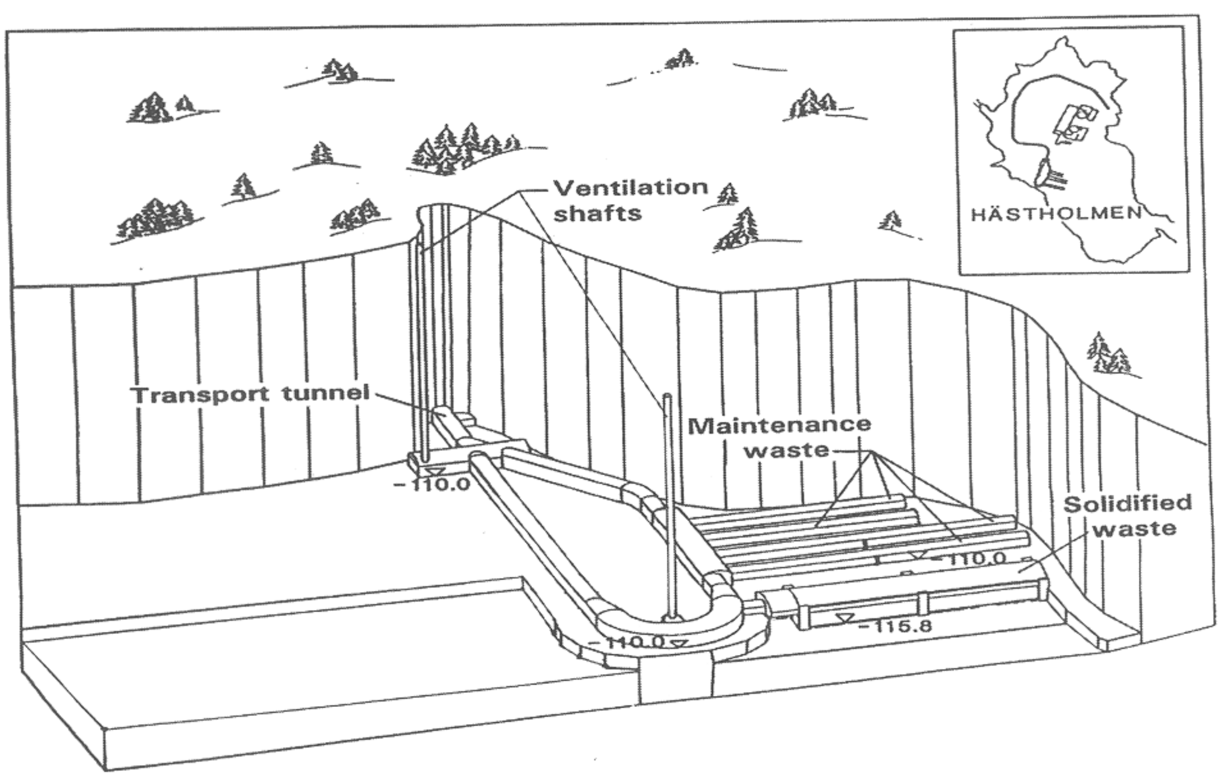


Figure 3. The low- and medium-level waste repository at Hästholmen Island, City of Loviisa. The repository is being constructed for IVO (courtesy of TVO).

practice of disposal for France's Category A waste was dumping in the north Atlantic ocean, which was discontinued in 1969. However, France's present strategy for disposal of LLW is near-surface disposal in engineered structures.

In France, the National Agency for Radioactive Waste (ANDRA) is responsible for finding and evaluating potential disposal sites, the Ministry of Industry is responsible for choosing a site from the list, and the selection is approved by the Prime Minister. Two sites have been used by ANDRA for LLW disposal: La Manche and Centre de l'Aube.

The La Manche disposal facility near the La Hague reprocessing plant has been in operation since 1969. In 1992, the near-surface disposal facility reached its full capacity of 0.5 million cubic meters. La Manche is located in a coastal climate with a groundwater table at a depth of 6 to 15 meters. The site was selected largely for reasons of convenience, and the geology of the site is complex and not ideal.

Initially, the waste was buried directly in two shallow trenches of plain earth with gravel on the bottom. The trenches were covered with soil, a plastic sheet, and another layer of soil. In 1976, regional monitoring revealed leaching of radionuclides from the La Manche site to a nearby stream. However, much more stringent safety criteria have been applied since 1978 with the employment of engineered structures.

After 1978 LLW was disposed of in rectangular concrete pits with drainage channels. The waste was completely encapsulated by backfilling the concrete to form a monolith, which was completed by pouring a concrete slab on the upper layer of the trench. Additional LLW containers were placed on top of the monolith with platforms and drainage channels. The containers were stacked 6 meters high, and the spaces were filled with gravel. A layer of impervious clay and topsoil covered the mound, which was then seeded with grass, creating a mound about 10 meters high. The disposal practice is often referred to as the "tumulus" concept (Schneider 1991). The La Manche facility was completely filled in 1992; control will be maintained for a period of 300 years. After 300 years, the radioactivity of the waste will have decreased to levels considered safe.

In 1984, ANDRA decided to build a new facility, the Centre de l'Aube, for the disposal of short-lived low- and medium-level waste (Figure 4). It began operation in mid-1992 at Soulaines Dhuys. The site was chosen based on its geology, consisting of an unsaturated layer of sand covering a thick layer of clay, and its well characterized hydrology, and because its performance could be easily modeled and shown to be acceptable. The facility should continue to operate for about 30 years based on an annual delivered volume of 35,000 cubic meters of LLW.

The l'Aube facility uses a disposal concept similar to La Manche. The primary difference between the new concept and the former concept is that at l'Aube, there will be no burial of LLW drums (i.e., no tumulus) on top of the concrete vaults. Instead, all waste will be emplaced in vaults with dimensions of 25 square meters, 8.5 meters high, and with 30-meter-thick walls. The vaults will be backfilled with gravel and sealed with a concrete roof (Schneider 1991). A final cap of clay, bitumen, and seeded topsoil will be placed over the structures.

The Federal Republic of Germany (FRG)

In Germany, disposal of radioactive waste is the responsibility of the Federal government. In 1976, the Physikalisch-Technische Bundesanstalt (PTB) was entrusted with the construction and operation of long-term storage and disposal facilities. In 1989 this responsibility was transferred to the newly founded Bundesamt fur Strahlenschutz (BfS). The strategy of the FRG, since the early 1960s, has been to dispose of all radioactive waste in deep geologic formations.

The FRG does not distinguish among low-level, intermediate-level (ILW), and transuranic radioactive waste, except by their rate of heat generation, for choice of disposal location. Both

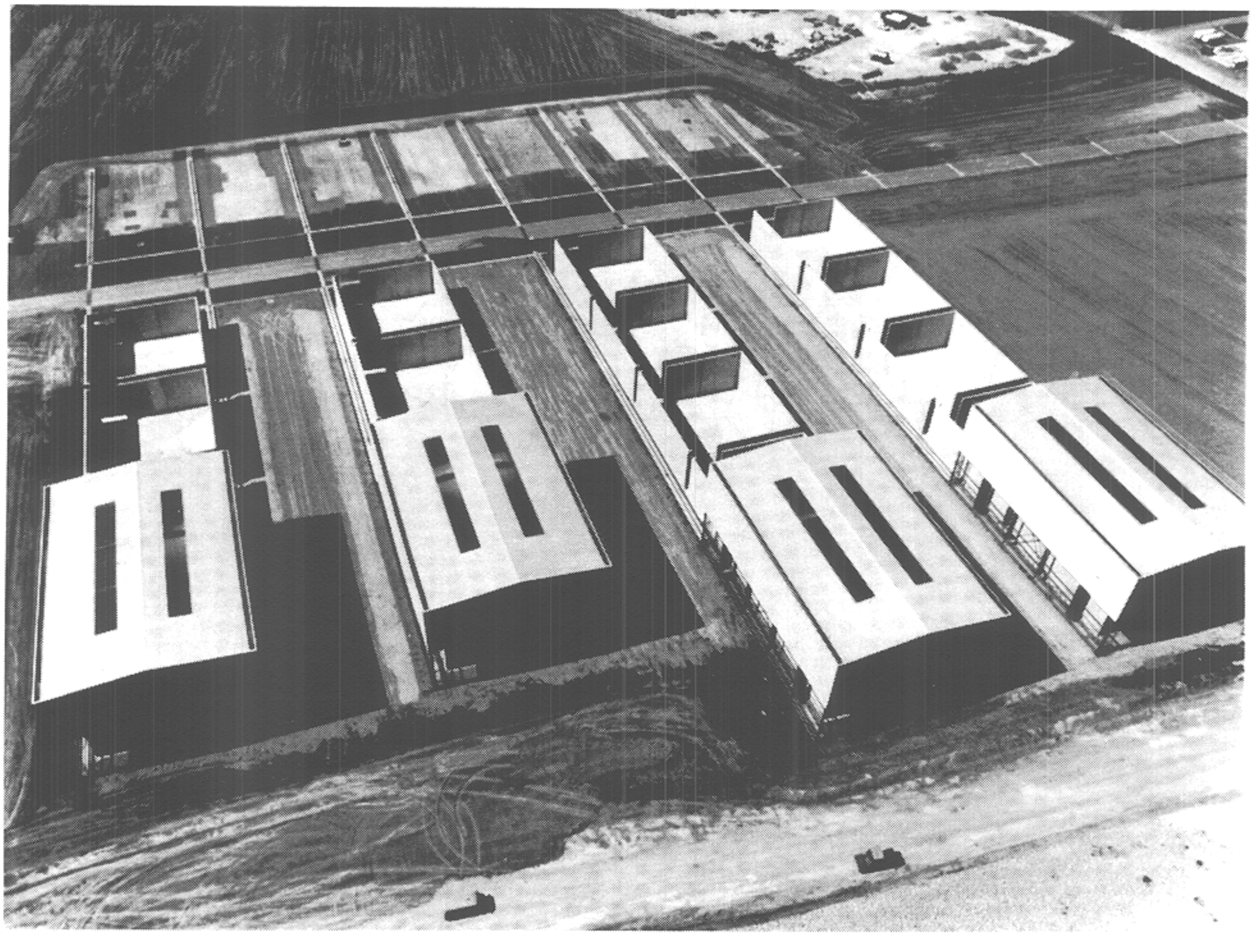


Figure 4. At Centre de l'Aube, waste packages are placed in engineered disposal structures resembling concrete vaults that are covered by movable buildings during loading (courtesy of ANDRA).

the Konrad and Gorleben repositories are designed to accept all radioactive waste, but waste with heat generation above a certain level must be placed in the Gorleben repository. For this reason, the Konrad repository is generally thought of as the ILW/LLW repository. Also, LLW has been disposed of in the Morsleben repository since the 1950s until the present, and in the Asse salt mine from 1967 to 1978.

The Morsleben repository is a former salt mine near Morsleben in the former German Democratic Republic (East Germany). It is at a depth of 400 to 600 meters and is situated in salt under a layer of clayey sediments. Three procedures have been used for disposal in the facility: (a) piling 200-liter drums in disposal chambers, (b) putting solid, unpackaged, or unconditioned waste directly into an underground cavity, and (c) in situ solidification of liquid LLW in a disposal cavity with concrete.

The Konrad repository is an abandoned iron ore mine that has been investigated to receive LLW (Figure 5). Development of the deep geological repository began in 1976; siting studies were conducted from 1976 to 1982; and underground exploration was performed from 1983 until 1986. The license application documents were submitted in 1986, and the revised versions were declared sufficient for public participation in 1990. It is estimated that the facility will be operational in 1996 if construction approval is granted in 1993. The operational period is estimated to be about 40 years.

The Konrad mine is located in sandstones surrounded by clayey sediments. The mine

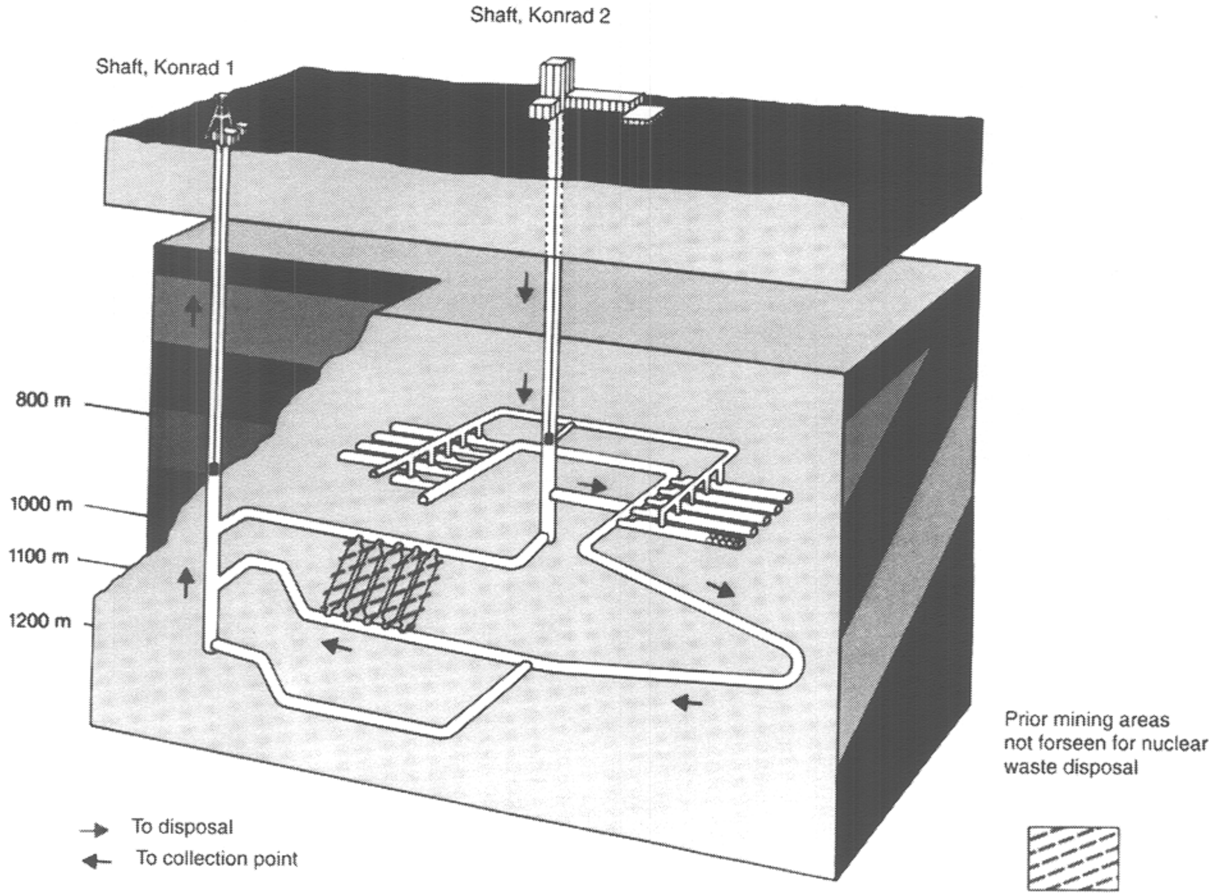


Figure 5. Schematic of Konrad repository (courtesy of BfS).

comprises six main levels situated at depths of 800 to 1,300 meters. The host-rock formation is a combination of porous and fissured media with low water permeability, which is dewatered by the mine openings driven into it. The mine is exceptionally dry, making it a reasonable choice for disposing of LLW. The waste will be stacked in a series of large-volume disposal tunnels that will be constructed along an inclined panel. The tunnels containing waste in drums will be backfilled and sealed (International Atomic Energy Agency 1992) (Figure 6).

Japan

The Federal government in Japan is responsible for regulating waste management practices, including disposal. However, the waste generators are responsible for disposing of LLW. Japan divides LLW into three types: (a) LLW for shallow burial that does not exceed 300 curies per metric ton for short half-life (i.e., cobalt-60), 30 curies per metric ton for cesium-137 and nickel-63, 20 curies per metric ton for strontium-90, 1.0 curies per metric ton for carbon-14, and 0.03 curies per metric ton for alpha-emitting nuclides that have very long half-lives (Schneider 1991); (b) LLW that results in public exposure of less than 1 millirem per year, considered to be below regulatory concern, can be buried as nonradioactive waste; (c) uranium-bearing LLW from uranium fuel fabrication, mining, and enrichment activities, defined as a special class of LLW whose disposal method is not yet settled.

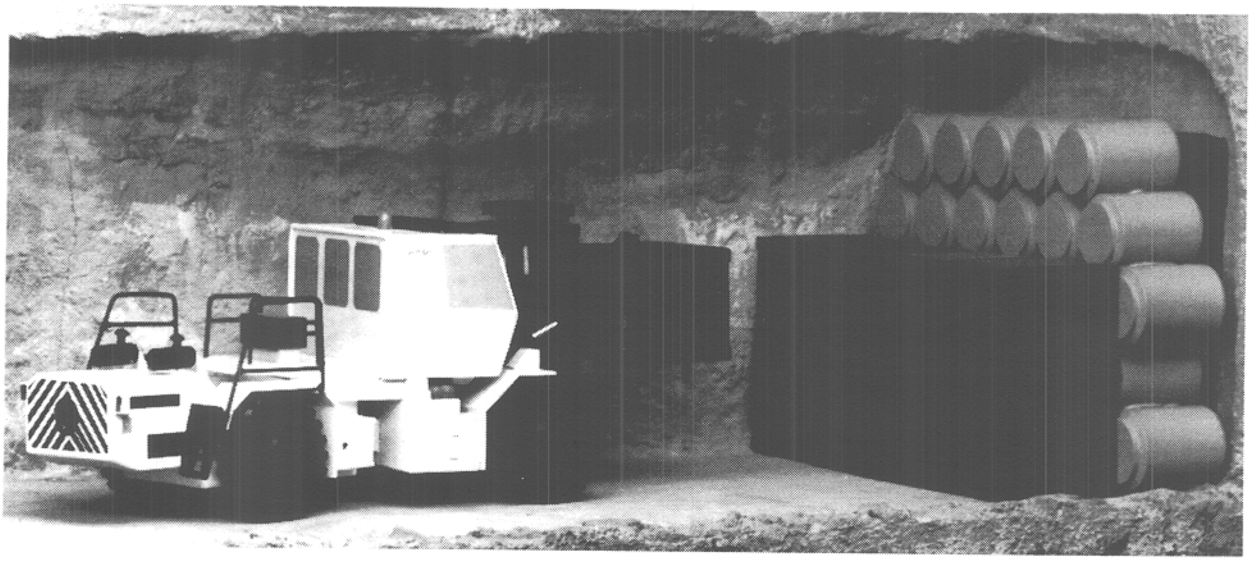


Figure 6. Model of waste packages within Konrad (courtesy of BfS).

Japan's official policy on disposal of LLW was formerly to use both land and sea disposal methods. However, Japan is a signatory of the London Dumping Convention and has promised to abide by its ruling to cease disposal of radioactive waste into the oceans. Therefore, LLW acceptable for shallow burial was being stored at the waste generators' site until a land facility was operational. The land facility that was chosen for disposal of LLW is at Rokkasho-mura, located on the northern tip of the main island of Japan, Honshu. The location is on a plateau 30 to 60 meters above sea level with the groundwater 2 meters below ground level.

On December 8, 1992, the Japan Nuclear Fuel Ltd. (JNFL) center at Rokkasho-mura, Aomori Prefecture, began accepting LLW for disposal (Figures 7 and 8). The facility will provide disposal capacity until 2030, then it will be further monitored for 300 years. The facility will accept 200-liter drums that are solidified with concrete. Following visual inspection, the drums will be placed into one of the 10 reinforced concrete pits using a sliding crane. One pit is composed of 16 compartments, and each compartment is designed to store 320 waste drums. JNFL plans to place mortar around and on top of the drums. In addition, a reinforced concrete cover will be placed over each pit. The burial area will be backfilled, and 4 meters of thick earth covering will be placed over the top of the pits (International Atomic Energy Agency 1993).

Sweden

The primary responsibility for waste management in Sweden lies with the owners of the reactors, including financing the total costs, which is achieved by a fee levied on nuclear electricity production. To fulfill the obligation, the four owners of the utilities have set up the jointly owned Swedish Nuclear Fuel and Waste Management Company (SKB). The SKB is responsible for the disposal of LLW from the power plants. LLW in Sweden is not differentiated by activity level; therefore, the International Atomic Energy Agency description that defines LLW as waste that can be handled and stored in simple packages without special protective measures is used.

Sweden's policy for LLW disposal is to use a single national repository called the Swedish Final Repository (SFR) located near the Forsmark nuclear power plant (Figure 9). Beginning operation in April 1988, the SFR is expected to reach full capacity in 2013. The repository is located underground in crystalline rock, about 60 meters under the Baltic Sea floor. SFR was situated under the sea to minimize the groundwater flow in the repository areas. The design of SFR consists of two 1-kilometer entrance tunnels that lead to the four

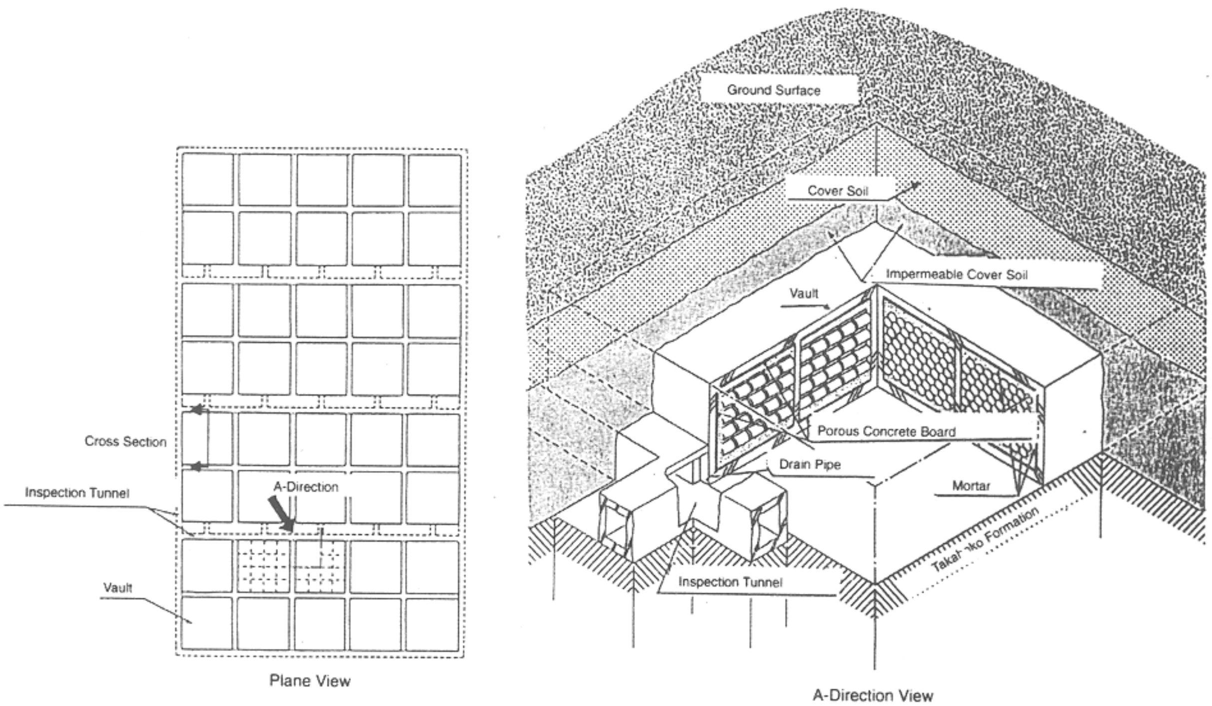


Figure 7. Outline of the disposal facilities (courtesy of JNFL).

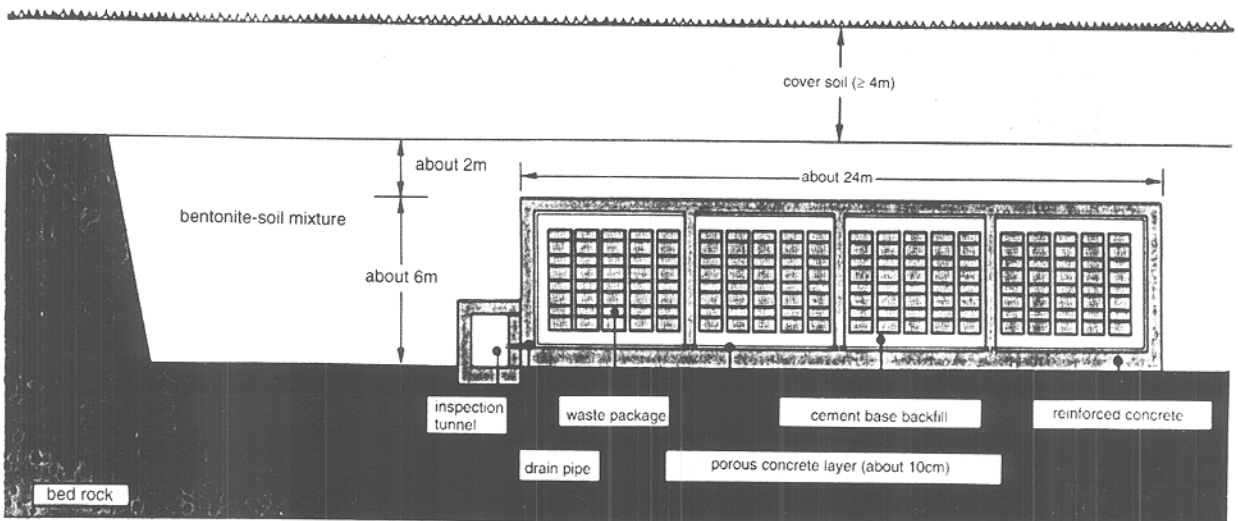
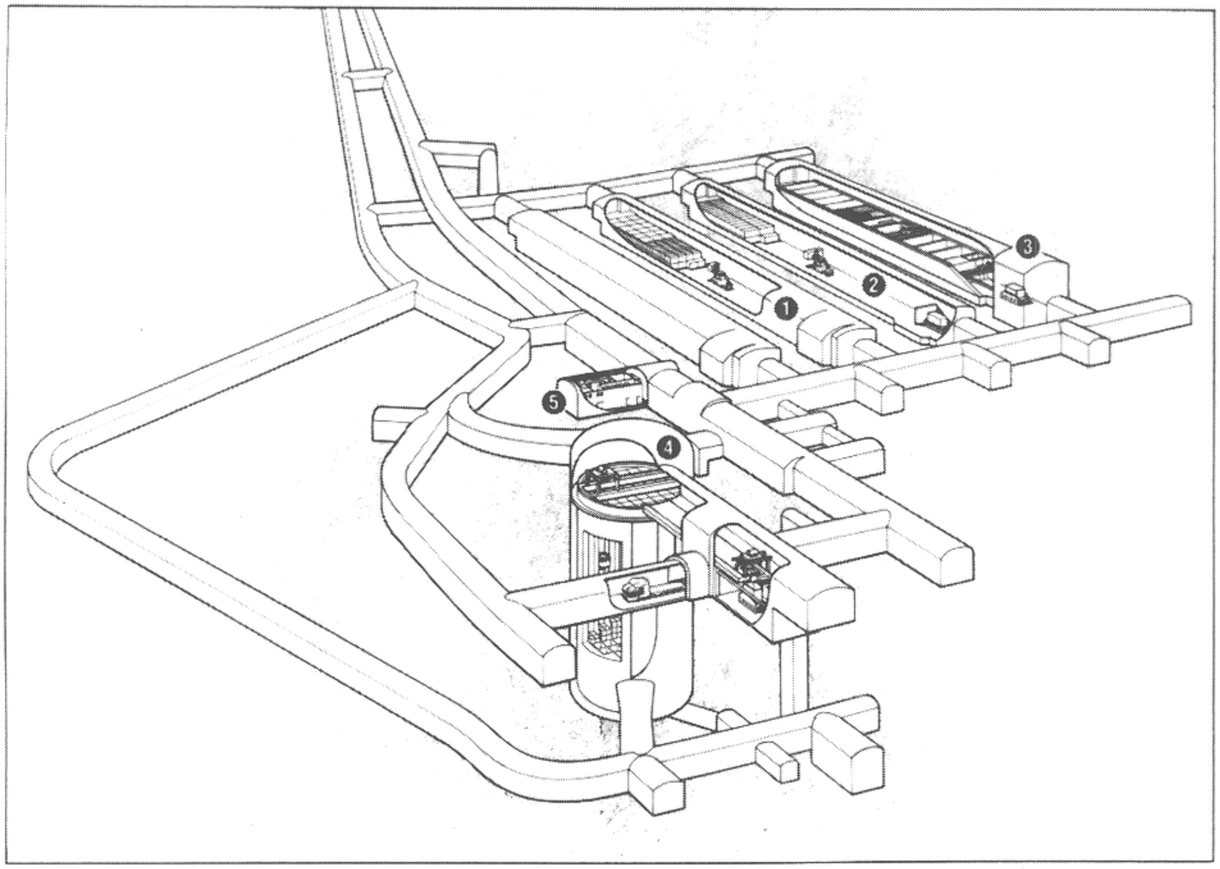


Figure 8. Cross section view of disposal facilities (courtesy of JNFL).



1. Rock vault for intermediate-level waste in concrete tanks. The tanks are handled by forklift truck.
2. Rock vault for low-level waste in freight containers. The containers are handled by forklift truck.
3. Rock vault with pits for intermediate-level waste in metal drums or moulds. The waste is handled by a remote-controlled overhead crane.
4. Silo for intermediate-level waste in metal drums or moulds. The waste is handled by a special remote-controlled handling machine.
5. Operating building with operations center and personnel quarters.

Figure 9. Schematic of SFR (courtesy of SKB).

rock vaults (Figure 10). One of the rock vaults will contain only LLW without any special radiation shielding; the other three vaults will contain intermediate-level radioactive waste. In addition, there is a concrete silo surrounded by a bentonite clay barrier that will contain the most radioactive waste. In fact, about 90% of the radioactivity in the repository will be disposed in the silo. When the facility has been filled, the entrance tunnels will be plugged with concrete to seal the caverns and prevent future access. There is no plan to monitor the repository after it is sealed.

Taiwan (Republic of China)

The Radwaste Administration (RWA) of Taiwan is an organization reporting to the Atomic Energy Council (AEC) with dual responsibilities: one as a regulatory body of the Radioactive Waste Management Council and the other one to operate the Lan-Yu LLW storage facility. LLW in Taiwan is defined according to surface dose rates of between 0.000005 and 0.2 millirem/hour on the LLW. Currently, LLW is being stored at the tropical island of Lan-Yu, which will store the waste for up to

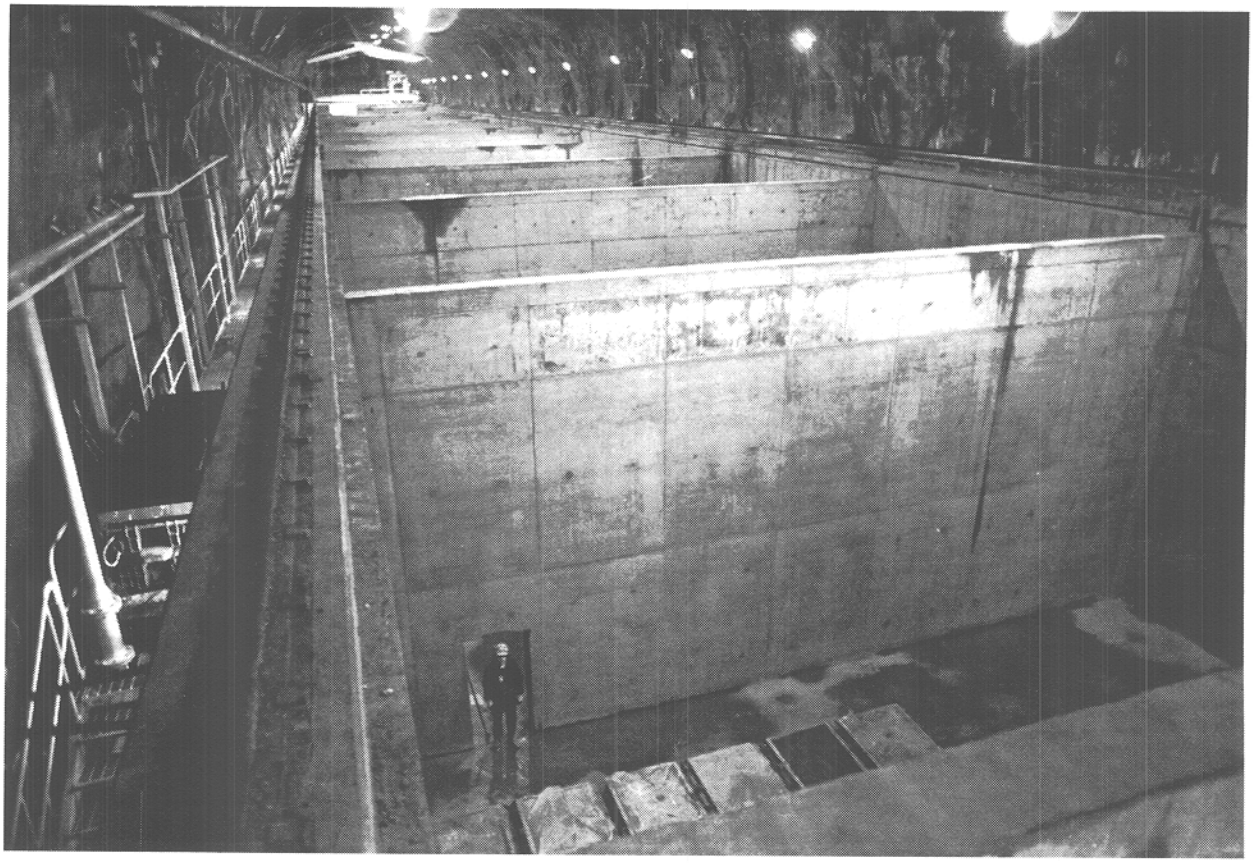


Figure 10. SFR divides its vaults into pits that contain the grouted waste packages (courtesy of SKB).

10 years until a permanent disposal concept is determined.

Ocean disposal of LLW is favored in Taiwan but has been postponed indefinitely because of the 1983 London Dumping Convention to ban ocean disposal. However, three sites within the 200-mile economic exclusion zone of Taiwan have been identified and are still under consideration if the international ban is lifted. The sites meet the following criteria: (a) the site must be within 200 miles of the shore; (b) it must have a vertical circulation cycle longer than 800 years; (c) the bottom at the target area should be covered with soft, fine-grained sediment, with a high sedimentation rate; (d) the sea floor should be stable and free from active faults and turbidity currents; (e) the ocean bottom density should be less than the waste package bulk density of 1.4; (f) the sea floor depth must be greater than 5,000 meters and be free of strong currents above the target areas; and (g) the site must be free from undersea cables and outside shipping routes. In the interim period, improved shallow burial at Lan-Yu is being investigated as a backup to ocean disposal (Schneider 1991).

United Kingdom

Responsibility for the development of a national strategy for the management of radioactive waste in the United Kingdom (UK) lies with the Secretary of State for the Environment. The task of developing an underground disposal facility for intermediate-level radioactive waste has been given to UK NIREX Limited, a company jointly owned by the nuclear utilities. The facility also will be designed to accommodate LLW. LLW in the UK is waste in which the specific radioactivity does not exceed 9.25 curies per metric ton of alpha activity (9.25 Ci/MT) or 3.1 Ci/MT beta-gamma activity, and are other than that waste suitable for disposal with household refuse. Presently, LLW is disposed of at British Nuclear Fuel Limited's (BNFL's) Drigg, near

Sellafield, although some disposal of low- and intermediate-level radioactive waste in the North Sea was done between 1949 and 1982. This practice has been discontinued due to international pressure although the UK maintains that the practice is both safe and practical.

Drigg is a shallow disposal site 4 miles southeast of Sellafield, West Cumbria, that began operations in 1959 (Figure 11). The facility is expected to accommodate all the LLW generated within the next 60 years. Originally, the waste was disposed of by tumble tipping into unlined trenches, and covering it with at least 1.5 meters of soil and aggregate to restore the site to its original level. In1987, major improvements were made that changed the disposal concept from trench burial to engineered structures (vaults). The allowed waste

Figure 11. Aerial view of BNFL's engineered concrete vaults at Drigg (courtesy of BNFL).

form for vault disposal has also changed to high force compacted waste in-fill grouted into 20 cubic meter steel overpacks. Construction of the first engineered storage vault was completed in late 1988. A feature of the design is that the concrete floor slab sits on an engineered clay base (Figure 12).

The UK has also been investigating potential sites for a deep geologic repository for the disposal of low- and intermediate-level radioactive waste. UK NIREX Limited is planning to construct an underground Rock Characterization Facility as the next stage of its investigations at the preferred site for this repository near Sellafield, West Cumbria.

Figure 12. Engineered concrete vault at BNFL's LLW disposal site at Drigg (courtesy of BNFL).

The necessary geological studies and construction of the facility will take at least 10 years. The Dounreay site remains the second-choice site should Sellafield prove technically unsuitable.

Conclusion

Disposal technologies in the countries studied are becoming increasingly sophisticated and technically sound. Disposal practices for LLW around the world are showing some trends toward shifting from shallow, earthen trenches to engineered barriers and concrete bunkers. Of the countries studied, Canada, China, France, Japan, and the UK have either modified previously existing trenches or developed new disposal facilities to incorporate engineered structures such as concrete trenches or pits. Other countries, such as Finland, Germany, and Sweden are disposing of LLW in hardrock areas. Taiwan does not yet have a disposal facility to use and is storing the waste until a permanent facility becomes available.

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